Procedure

Acceleration noise due to thermal effects occurs through three different phenomena - the radiometer effect, thermal radiation pressure, and differential outgassing.

Radiometer effect: In low pressure gas systems, the mean free path between molecules is large and interactions are few. Thus, the only exchange of energy is due to boundary interactions. When a molecule bounces into the electrode housing face and sticks, it exchanges heat energy with the face due to a temperature difference and is reemitted at a different energy. With the area A, Pressure P, and gas average temperature T\_0, the radiometer effect force per degree K is given as

\begin{equation}

\frac{dF}{dT}\_{Radio}=\frac{A P}{4 T\_{0}}.

\end{equation}

In this system it is assumed the faces in the measuring axis are not the same temperature and thus molecules at the hotter side will be reemitted at a higher energy, causing a differential pressure in the electrode housing. The analytical calculation for the radiometer effect is 7.68x10^{-12} N/K.

Thermal Radiation Pressure: Thermal Radiation Pressure is the pressure induced by electromagnetic radiation. More heat energy causes greater radiation, so a differential temperature gradient would therefore exert a force due to radiation on the Test Mass. With the Stephan Boltzmann constant k\_B and speed of light c, the radiation pressure force per degree K is given as

\begin{equation}

\frac{dF}{dT}\_{RP}=\frac{8 A k\_{B}}{3 c T\_{0}^{3}}.

\end{equation}

The analytical calculation for the radiation pressure is 1.14x10^{-11} $N/K$.

Differential Outgassing: All materials are saturated with gas on their surface. At different thermodynamic states, this level of saturation changes and can cause outgassing - the desorption of particles sticking to a surface. A higher temperature leads to increased outgassing, therefore a differential temperature gradient causes more gas on one side than the other, leading to a pressure difference that exerts a force. With outgassing rate $I\_{o}$, activation temperature $\theta$, and gas conductance $C\_{eff}$, the outgassing force per degree $K$ is given as

\begin{equation}

\frac{dF}{dT}\_{RP}=\frac{8 A k\_{B}}{3 c T\_{0}^{3}}.

\end{equation}

The analytical calculation for the outgassing is 3.67x10^{-11} $N/K$.

Simulation:

A Monte Carlo physics based simulation was conducted using the Molflow software produced by CERN. The software was used to replicate analytical calculations with simulated results. Simulations were first performed in an attempt to replicate the radiometer effect has been studied for over 100 years and is well understood. This provided a foundation to provide more confidence in results obtained for the outgassing effect. Outgassing is a less understood phenomena, and simulations were really wanted to confirm the effect magnitude.

The radiometer simulation involved a simplified geometry of the GRS that did not contain the GPRM facets. A uniform outgassing was applied to every surface of the geometry. The sticking factor applied was 0.75. Data suggested that a sticking factor above 0.6 and below 0.9 was appropriate, and thus 0.75 was chosen. Simulations confirmed this was an accurate representation. The holes had a sticking factor of 1 applied to them, implying that any molecule that hits the hole would leave the system. A temperature gradient of 5 K was applied to opposite faces in the measuring axis, with the mean temperature being 293.15 K. The pressures on the opposite test mass faces in the measuring axis were collected and evaluated. With face pressures $P\_{1}$ and $P\_{2}$, test mass face area $A$, and temperature difference $dT$, the radiometer force per unit temperature solution is

\begin{equation}

\frac{dF}{dT}\_{R}=\frac{(P\_{1}-P\_{2}) A}{dT}.

\end{equation}

The simulation results at 10^{-5} Pa provided a $N/K$ of $7.61 \times 10^{-12}$. This shows the agreement between the simulation and analytical results, and can be applied to outgassing.

The outgassing inputs were obtained from [Mance]. The simulation was set up similar to the radiometer setup, but there were a few key differences. Rather than have a uniform outgassing rate, each face had an outgassing rate accounting for the temperature difference. The outgassing rates were calculated using

\begin{equation}

Q = I\_{0} e^{-\frac{\theta}{T\_{0}}}.

\end{equation}

To establish a more solid value for the outgassing force per temperature difference, the temperature differences were varied. Simulations were performed for 1, 2.5, 4, and 5 K. The simulations agreed with each other, showing a clear temperature dependence. An outgassing simulation was completed for LPF geometry in an attempt to match the results in the experiment detailed in [Mance]. The results were close to those, and therefore the same inputs were used for the LPF geometry. The simulated result for the GRACE geometry was $5.7 \times 10^{-13}$.

This shouldbeσ= 5.67×10−8instead ofkb= 1.38×10−23, right?



